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Influence of magnetic field on peristaltic flow of a Casson fluid in an asymmetric channel: Application in crude oil refinement

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ABSTRACT

The influence of magnetic field on peristaltic flow of a Casson fluid model is considered. The model for peristaltic literature is modelled first time. The governing coupled equations are constructed under long wavelength and low Reynold's number approximation. Exact solutions are evaluated for stream function and pressure gradient. The important findings in this study are the variation of the Hartmann number M, Casson fluid parameter ζ and amplitudes a, b, d and ϕ. The velocity field increases due to increase in Hartmann number M near the channel walls while velocity field decreases at the centre of the channel.

1. Introduction

Fluid flows under the influence of applied magnetic field are apparent in certain engineering processes like glass manufacturing, Crude Oil refinement, paper production and in some geophysical studies. The influence magnetic field on peristaltic transport of a Newtonian fluid in a vertical annulus with application of an endoscope is presented by Mekheimer and Elmaboud [1]. Ebaid [2] discussed the similar kind of situation under the influence of applied magnetic field in circular tube. MHD peristaltic flow through a porous space with compliant walls is debated by Srinivas and Kothandapani [3]. In another paper Srinivas et al. [4] studied the influence of slip conditions, wall properties and heat transfer on MHD peristaltic transport. Ellahi et al. [5] presented the analytical solutions for MHD flow in a third-grade fluid with variable viscosity. Very recently effects of MHD on Cu–water nanofluid flow and heat transfer by considering lorentz force is coated by Sheikholeslami et al. [6,7]. Peristaltic motion of Oldroyd fluid in an asymmetric channel with MHD is investigated by Ellahi et al. [8]. They modelled the problem and then the analytical solutions of coupled equations are developed by regular perturbation method. Abd-Alla et al. [9,10] presented combined effects of rotation and magnetic field in peristalsis for different non-Newtonian fluids.

The wavelike muscular contractions of the alimentary canal or other tubular structures by which contents are forced onward toward the opening is known as peristalsis. Initiated work for peristaltic flow has been done by Latham [11] and Shapiro et al. [12]. Peristaltic flows has a wide range of applications like urine transport from kidney to bladder, movement of chyme in the gastrointestinal tract, transport of spermatozoa in the ducts efferent of the male reproductive tract and in the cervical canal, in the movement of ovum in the female fallopian tube, transport of lymph in the lymphatic vessels and in the vasomotion of small blood vessels such as arterioles, venules and capillaries, keeping these practical applications in mind researchers have put their attentions towards peristaltic flows i.e. [13–20]. Further literature on the topic can be viewed through Refs. [21–30].

The MHD Peristaltic flow of a Casson fluid [20] model is considered. The model for peristaltic literature is modelled first time. The governing coupled equations are constructed under long wavelength and low Reynold's number approximation. Exact solutions are evaluated for stream function and pressure gradient. The important findings in this study are the variation of the Hartmann number M, Casson fluid parameter ζ and amplitudes a, b, d and ϕ. The velocity field increases due to increase in Hartmann number M near the channel walls while velocity field decreases at the centre of the channel.

2. Basic flow equations

Here we discussed an incompressible *MHD* Casson fluid in an asymmetric channel with channel width $d_1 + d_2$. Sinusoidal wave propagating with constant speed c along the walls of the channel. Asymmetric in the channel flow is retained due to the following wall surfaces expressions:

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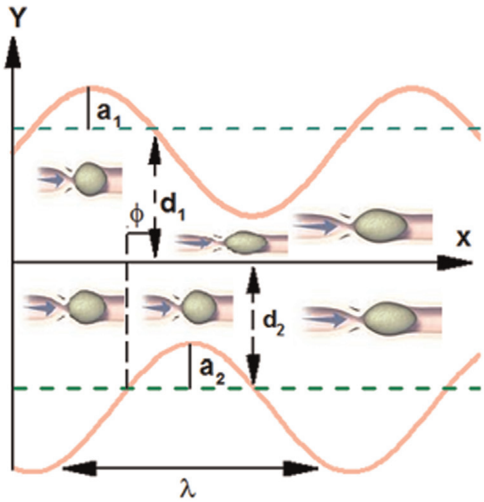

Fig. 1. Geometry of the problem.

$$Y = \bar{H}_1 = d_1 + a_1 \cos\left[\frac{2\pi}{\lambda}\left(X - ct\right)\right],$$

$$Y = \bar{H}_2 = -d_2 - b_1 \cos\left[\frac{2\pi}{\lambda}\left(X - ct\right) + \phi\right]. \quad (1)$$

In the above equations a_1 and b_1 denote the waves amplitudes, λ is the wave length, $d_1 + d_2$ is the channel width, c is the wave speed, t is the time, X is the direction of wave propagation and Y is perpendicular to X. The expression for fixed and wave frames is related by the following relations

$$\bar{x} = \bar{X} - ct, \quad \bar{y} = \bar{Y}, \quad \bar{u} = \bar{U} - c, \quad \bar{v} = \bar{V}, \quad p(\bar{x}) = P(\bar{X}, t). \quad (2)$$

The constitutive equation for Casson fluids [20] is defined as follows:

$$\tau^{1/n} = \tau_0^{1/n} + \mu\dot{\gamma}^{1/n} \quad (3)$$

$$\tau_{ij} = \left(\mu_B + \sqrt{2\pi_c}/p_y\right)2e_{ij}$$

where p_y is yield stress and $\pi = e_{ij}$, e_{ij} is the (i, j) component of deformation rate, μ_β is the plastic viscosity of the fluid. For ordinary fluid $\left(p_y = 0\right)$, we have

$$e_{ij} = \frac{1}{2}\left(\frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial yi}\right). \quad (4)$$

we introduce the following non-dimensional quantities:

$$x = \frac{2\pi\bar{x}}{\lambda}, y = \frac{\bar{y}}{d_1}, \quad u = \frac{\bar{u}}{c}, \quad v = \frac{\bar{v}}{c}, \quad t = \frac{2\pi\bar{t}}{\lambda}, \quad \delta = \frac{2\pi d_1}{\lambda},$$

$$d = \frac{d_2}{d_1}, \quad P = \frac{2\pi d_1^2 P}{\mu c\lambda}, h_1 = \frac{\bar{h}_1}{d_1}, \quad h_2 = \frac{\bar{h}_2}{d_2}, \quad Re = \frac{\rho c d_1}{\mu},$$

$$a = \frac{a_1}{d_1}, \quad b = \frac{a_2}{d_1}, \quad d = \frac{d_2}{d_1}, \quad S = \frac{\bar{S}d_1}{\mu c}, \zeta = \mu_\beta\sqrt{2\pi_c}/p_y. \quad (5)$$

where ζ denotes the Casson fluid parameter.

Stream function and velocity field are related by the expressions

$$u = \frac{\partial\Psi}{\partial y}, \quad v = -\delta\frac{\partial\Psi}{\partial x},$$

In view of Eqs. (2)–(5) under the long wavelength and low Reynolds number assumption we have the following equations:

$$\left(1 + \frac{1}{\zeta}\right)\frac{\partial^4\Psi}{\partial y^4} - M^2\frac{\partial^2\Psi}{\partial y^2} = 0, \quad (6)$$

$$\frac{dP}{dx} = \frac{\partial}{\partial y}\left[\left(1 + \frac{1}{\zeta}\right)\frac{\partial^2\Psi}{\partial y^2} - M^2\left(\Psi + 1\right)\right], \quad (7)$$

The non-dimensionless boundary conditions

$$\Psi = \frac{F}{2}, \quad \frac{\partial\Psi}{\partial y} = -1 \quad \text{at } y = h_1 = 1 + a\cos x, \quad (8a)$$

$$\Psi = -\frac{F}{2}, \quad \frac{\partial\Psi}{\partial y} = -1 \quad \text{at } y = h_2 = -d - b\cos\left(x + \phi\right), \quad (8b)$$

The flow rates in fixed and wave frame are related by

$$Q = F + 1 + d. \quad (9)$$

3. Solution profiles

Exact solutions for stream function, temperature profile, nanoparticle fraction and pressure gradient can be written as

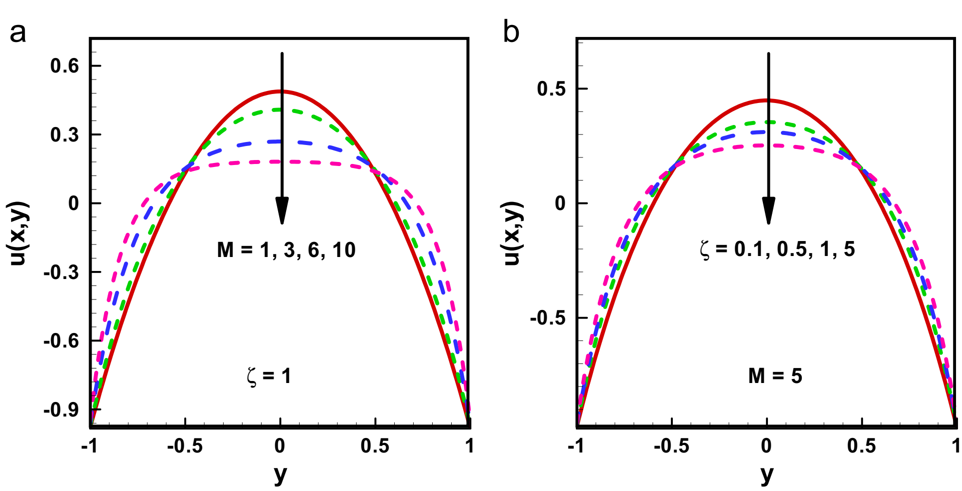

Fig. 2. Velocity profile for different values of Hartmann number M and Casson parameter ζ.